# HTurbo: Fast predictions for Higgs production at the LHC

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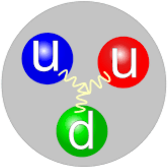
# Outline

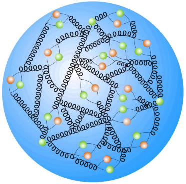
1. QCD in a nutshell
   - Factorization in QCD
   - Partonic cross section
   - Perturbative QCD
2. Resummation in QCD
   - Higher order corrections
   - Resummation of $q_\perp$
3. HTurbo
   - Higgs production at the LHC: HRes and HqT
   - HTurbo: Fast predictions for Higgs production
   - Results & Conclusions

## QCD in a nutshell

# QCD in a nutshell

## Address nuclear structure

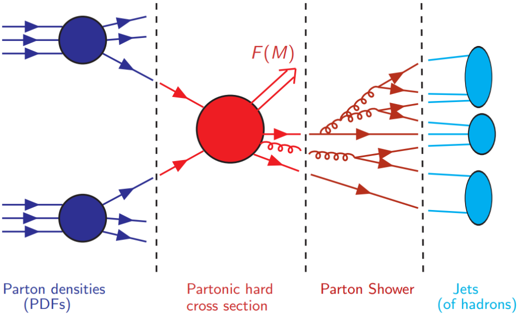


- Hadrons made of partonic objects $\longrightarrow$ non perturbative physics
- Smash two hadrons to explore internal structure $\longrightarrow$ LHC physics
- Compute cross section is a hard problem $\longrightarrow$ QCD Factorization

# QCD in a nutshell

## Factorization theorem

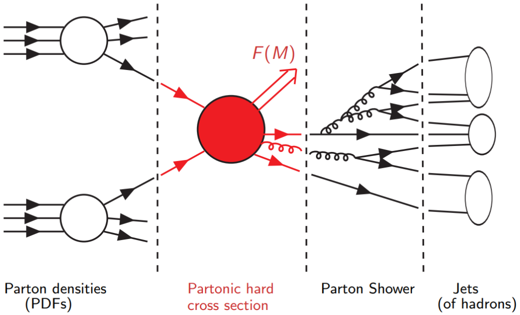



Factorization in QCD $\longrightarrow$ Convolute the PDFs with the partonic $\hat{\sigma}^{\mathrm{F}}_{\alpha\beta}$

$$\sigma^{\mathrm{F}}(p_1, p_2) = \int_0^1 dx_1 dx_2\, f_\alpha(x_1, \mu_F^2) * f_\beta(x_2, \mu_F^2) * \hat{\sigma}^{\mathrm{F}}_{\alpha\beta}(x_1 p_1, x_2 p_2, \alpha_s(\mu_R^2), \mu_F^2)$$

# QCD in a nutshell

## Partonic cross section

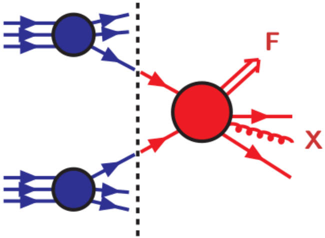



- PDFs $f_\alpha(x_i, \mu_F^2)$ absorb the non perturbative effects, evaluated at $\mu_F$
- Partonic $\hat{\sigma}^{\mathrm{F}}_{\alpha\beta}$ can be computed as perturbative series in $\alpha_s$

# QCD in a nutshell

## Perturbative QCD

- Born cross section as LO value of a perturbative series
- $\sigma^{(1)}, \sigma^{(2)}, \sigma^{(3)}$ are the NLO, NNLO, N3LO corrections




$$\hat{\sigma} = \sigma^{\texttt{Born}} \left( 1 + \frac{\alpha_s}{2\pi}\sigma^{(1)} + \left(\frac{\alpha_s}{2\pi}\right)^2 \sigma^{(2)} + \left(\frac{\alpha_s}{2\pi}\right)^3 \sigma^{(3)} + \dots \right)$$

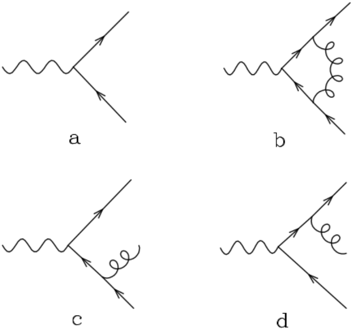
Leading order predictions can strongly depend on the renormalization and factorization scales → Need higher order corrections

## Resummation in QCD

# Resummation in QCD

## Higher order corrections

1. Higher order corrections are not an easy task due to infrared (IR) singularities
2. Soft and collinear singularities
3. Impossible direct use of numerical techniques

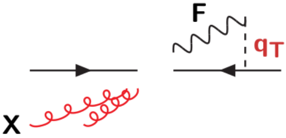


# Resumation in QCD

## $q_\perp$ resummation

Produce a final state from hadron collisions and study the $q_\perp$ distribution

$$h_1(p_1)+h_2(p_2) \longrightarrow F(M, q_\perp)+X$$




| | | | |
|---|---|---|---|
| $\alpha_S L^2$ | $\alpha_S L$ | $\cdots$ | $\mathcal{O}(\alpha_S)$ |
| $\alpha_S^2 L^4$ | $\alpha_S^2 L^3$ | $\cdots$ | $\mathcal{O}(\alpha_S^2)$ |
| $\cdots$ | $\cdots$ | $\cdots$ | $\cdots$ |
| $\alpha_S^n L^{2n}$ | $\alpha_S^n L^{2n-1}$ | $\cdots$ | $\mathcal{O}(\alpha_S^n)$ |
| dominant logs | $\cdots$ | $\cdots$ | $\cdots$ |

Truncated fixed order predictions $\rightarrow$ divergent $\alpha_s^n \ln^m(M^2/q_\perp^2)$ appear.

Replace partonic $q_\perp$ distribution as follows

$$\frac{d\hat{\sigma}_{ab}}{dq_\perp^2} \to \left[\frac{d\hat{\sigma}_{ab}^{(\mathrm{res.})}}{dq_\perp^2}\right]_{\mathrm{l.a.}} + \left[\frac{d\hat{\sigma}_{ab}^{(\mathrm{fin.})}}{dq_\perp^2}\right]_{\mathrm{f.o.}}$$

such that

$$\int dq_\perp^2 \frac{d\hat{\sigma}_{ab}^{(\mathrm{res.})}}{dq_\perp^2} \sim \sum \alpha_s^n \log^m \frac{M^2}{Q_\perp^2} \quad \mathrm{for} \qquad q_\perp \to 0$$

$$\int dq_\perp^2 \frac{d\hat{\sigma}_{ab}^{(\mathrm{fin.})}}{dq_\perp^2} \sim 0 \quad \mathrm{for} \qquad q_\perp \to 0$$

# Resummation in QCD

## $q_\perp$ resummation

Resummation holds in impact parameter space $b$

$$\frac{d\hat{\sigma}^{\text{res.}}_{ab}}{dq_\perp^2} = \frac{M^2}{\hat{s}} \int db\, \frac{b}{2}\, J_0(bq_\perp)\, \mathcal{W}_{ab}(b, M)$$

Which is expressed in Mellin space (with respect to $z = M^2/\hat{s}$)

$$\mathcal{W}_N(b, M) = \mathcal{H}_N(\alpha_s) \times exp\{\mathcal{G}_N(\alpha_s, L)\} \quad \text{being} \quad L \equiv \log(M^2 b^2)$$

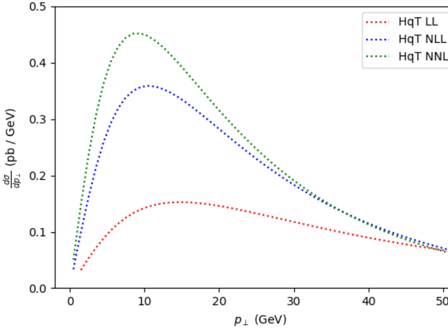
- Resummed effects exponentiated in a universal Sudakov factor
- Process-dependence factorized in the hard factor

HTurbo: Fast predictions for Higgs production

# HqT and HRes

## Predictions for Higgs $q_\perp$ distribution

- HqT and HRes [de Florian, G.F., Grazzini, Tommasini] produce $q_\perp$ distributions
- Higher order corrections require high computation times
- Codes producing fast predictions are needed for precision era of the LHC



# HTurbo

## Starting point DYTurbo

Start from **DYTurbo** [Camarda et al.] ref. at 1910.07049, producing $q_\perp$ distribution fro Drell-Yan ($q\bar{q} \to l^+ l^-$)

- Set LO amplitude to be $gg \to H$
- Set Sudakov and Hard coefficients for Higgs production
- Compare with **HRes** and **HqT**

# HTurbo

## Starting point DYTurbo

- Set LO amplitude to be $gg \to H$
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$$\mathcal{G}(\alpha_s, L) = L\, g^{(1)}(\alpha_s L) + g^{(2)}(\alpha_s L) + \frac{\alpha_s}{\pi} g^{(3)}(\alpha_s L) + \ldots$$

$$\mathcal{H}(\alpha_s) = 1 + \frac{\alpha_s}{\pi}\mathcal{H}^{(1)} + \left(\frac{\alpha_s}{\pi}\right)^2 \mathcal{H}^{(2)} + \ldots$$

Build predictions up to NNLO

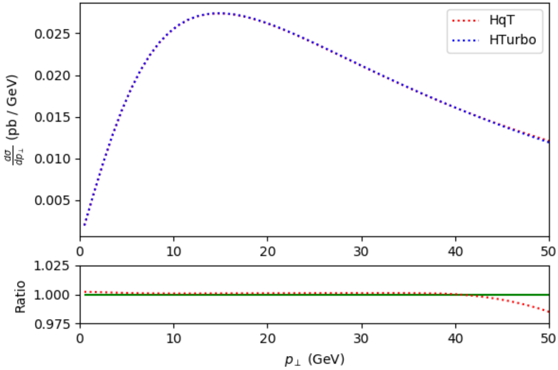
$$\mathrm{LL}(\sim \alpha_s^n L^{n+1}) : g^{(1)}, \hat{\sigma}^{(0)}$$

$$\mathrm{NLL}(\sim \alpha_s^n L^{n}) : g^{(2)}, \mathcal{H}^{(1)}$$

$$\mathrm{NNLL}(\sim \alpha_s^n L^{n-1}) : g^{(3)}, \mathcal{H}^{(2)}$$

# Results

## Comparison HTurbo and HqT




- HTurbo produces qt distributions that match HRes and HqT
- Excellent numerical agreement up to the $1/1000$

# Results

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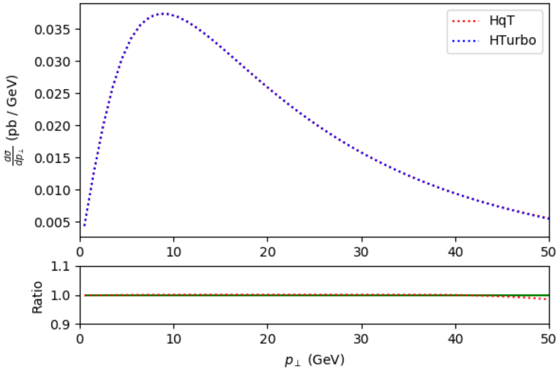


- Excellent numerical agreement up to the 1/1000
- Perfect agreement when switching off PDF evolution

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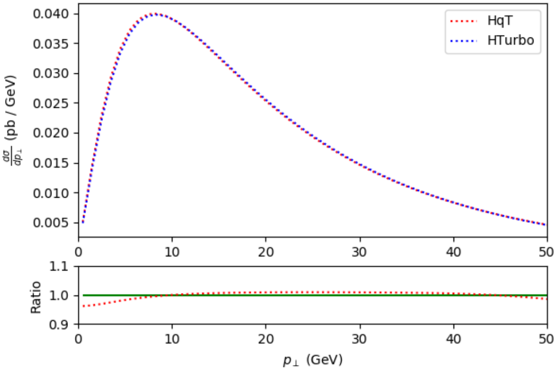


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# Results

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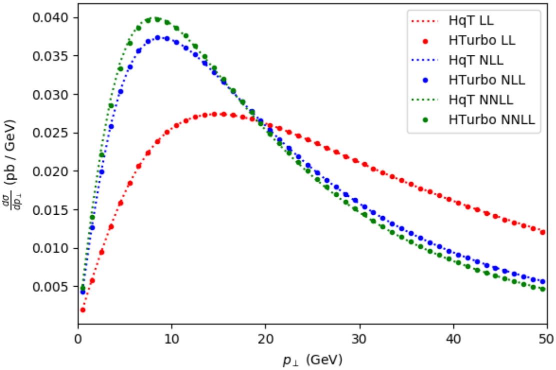


- Excellent numerical agreement up to the 1/1000
- Perfect agreement when switching off PDF evolution

# Summary & Conclusions

1. Fast predictions are required towards the precision era of the LHC
2. HTurbo produces qt distributions that perfectly match HRes and HqT
3. Predictions by HTurbo are much faster than any of the existing codes
4. Next steps: Implement PDF evolution N3LO distributions

Thank you!

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