HTurbo: Fast predictions for Higgs production at the LHC

Jesús Urtasun Elizari

PhD seminar - Milan, September 2020

UNIVERSITÀ DEGLI STUDI DI MILANO

N3PDF Machine Learning • PDFs • QCD

European Research Council

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 740006.

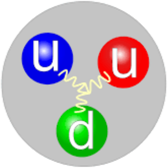
Outline

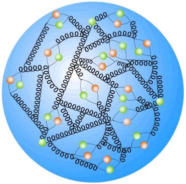
1. QCD in a nutshell
   - Factorization in QCD
   - Partonic cross section
   - Perturbative QCD
2. Dealing with divergences
   - Higher order corrections
   - Resummation in QCD
3. HTurbo
   - Higgs production at the LHC: HRes and HqT
   - HTurbo: Fast predictions for Higgs production
   - Results &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

QCD in a nutshell

QCD in a nutshell

Address nuclear structure

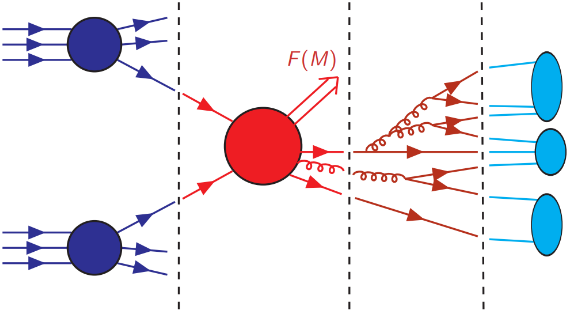




- Hadrons made of partonic objects $\longrightarrow$ non perturbative physics
- Smash two hadrons to explore internal structure $\longrightarrow$ LHC physics

QCD in a nutshell

Factorization theorem

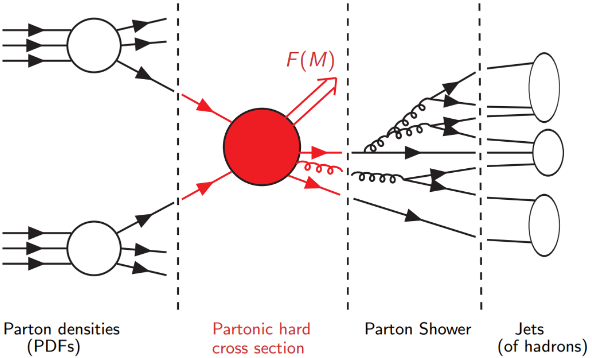


Factorize the problem $\longrightarrow$ Convolute the PDFs with the partonic $\hat{\sigma}_{ij}$

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

QCD in a nutshell

Factorization theorem



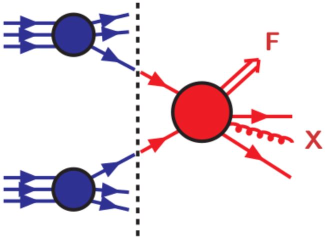
Factorize the problem $\longrightarrow$ Convolute the PDFs with the partonic $\hat{\sigma}_{ij}$

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

Partonic cross section and pQCD

Perturbative QCD

- Factorization theorem helps us to understand short range interactions
- Write cross section as a perturbative series



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

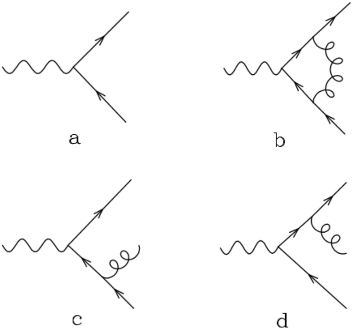
Leading order predictions can strongly depend on the renormalization and factorization scales → Need higher order corrections

Dealing with divergences

Perturbative 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

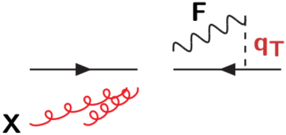


Resummation in QCD

Resumming large logs

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

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



Truncated fixed order predictions $\rightarrow$ divergent $\ln^m(M^2/q_\perp^2)$ appear.
Then the $q_\perp$ distribution need to be evaluated by replacing the partonic cross section as follows

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

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

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

Resummation in QCD

$q_\perp$ subtraction

Resummation holds in impact parameter space b

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

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

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

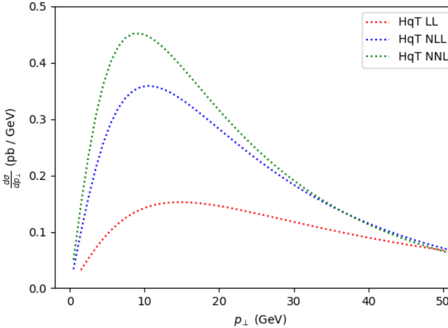
- Resummed effects exponentiated in a universal Sudakov factor
- Process-dependence factorized in the hard factor

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 time
- Codes producing fast predictions are needed for precision era of the LHC



HTurbo

Higgs distribution from Drell-Yan

Start from DYTurbo [Camarda et al.] ref. at 1910.07049 and /dyturbo

1. Matrix element $gg \to H$ as LO amplitude
2. Set Sudakov and Hard coefficients for Higgs production

$$\mathcal{G}(\alpha_s, L) = L\, g^{(1)}(\alpha_s L) + g^{(2)}(\alpha_s L) + \frac{\alpha_s}{\pi} g^{(3)}(\alpha_s L) + \ldots$$

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

Build predictions up to NNLO

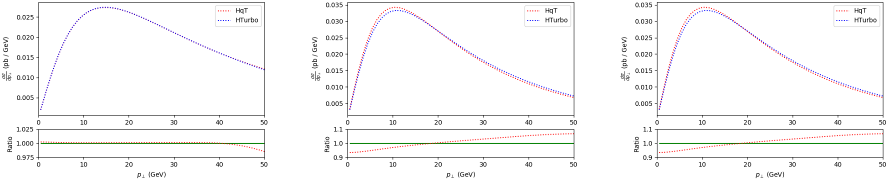
$$\mathrm{LL}(\sim \alpha_s^n L^{n+1}) : g^{(1)}, \hat{\sigma}^{(0)}$$

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

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

Results

Comparison HTurbo and HqT



- HTurbo produces qt distributions that match HRes and HqT
- Discrepancy at the 1/1000 level at NLL, at the 1/10 for NLL

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!

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 740006.