HTurbo: Fast predictions for Higgs production at the LHC

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Machine Learning • PDFs • QCD

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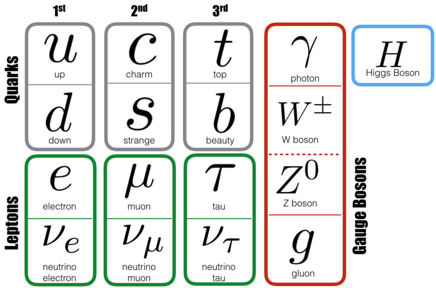
Outline

1. QCD in a nutshell
   - The Standard Model & strong interactions
   - Running QCD coupling
   - Factorization theorem
2. Dealing with divergences
   - Perturbative QCD and series expansion
   - Fixed order calculations
   - Resummation
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

The Standard Model



Quantum Field Theory describing physics at the TeV scale

1. Fermions composing matter
2. Bosons mediating interactions
3. Scalar Higgs generating mass

QCD in a nutshell

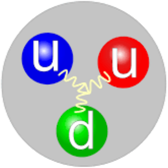
Explore the strong interactions

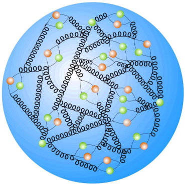
How to explore proton's inner structure?

- Point-like projectile on the object $\longrightarrow$ DIS
- Smash the two objects $\longrightarrow$ LHC physics

"A way to analyze high energy collisions is to consider any hadron as a composition of point-like constituents $\longrightarrow$ **partons"** R.Feynman, 1969

QCD in a nutshell
Parton Distribution Functions





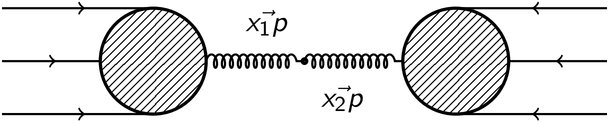
- Hadrons made of partonic objects $\longrightarrow$ non perturbative physics
- Interactions take place only at partonic level $\longrightarrow$ asymptotic freedom
- Running coupling given by Renormalization Group Equation (RGE)

$$\mu\frac{d\alpha(\mu)}{d\mu} = \beta(\alpha_s(\mu)) = -\sum_{n=0}^{\infty}\beta_n\left(\frac{\alpha_s}{\pi}\right)^{n+1}$$

QCD in a nutshell

Factorization theorem

Observables in hadronic events $\longrightarrow$ σ is hard to compute



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

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

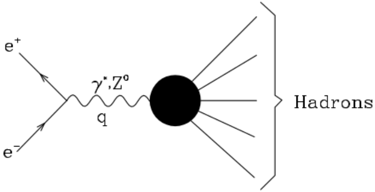
- Partonic $\hat{\sigma}$ can be computed as perturbative series in α_s
- PDFs absorb the non perturbative effects, evaluated at μ_F

Dealing with divergences

Partonic cross section and pQCD

Why do we need series expansion?

1. QCD in e+e- collisions
2. Measure only hadrons in the final state
3. Factorization theorem helps us to understand short range interactions

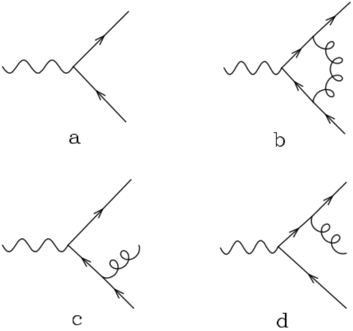


Write the cross section as a perturbative series

Perturbative QCD

Higher order corrections

1. QCD in e+e- collisions
2. Measure only hadrons in the final state
3. Factorization theorem helps us to understand short range interactions



$$\sigma_{q\bar{q}g} = C_F \frac{\alpha_s}{2\pi} \sigma_{q\bar{q}^{\mathrm{Born}}} \int d\cos\theta \frac{dl^0}{l} \frac{4}{(1 - cos\theta)(1 + cos\theta)}$$

Fixed Order computations diverge!

Resummation in QCD

Resumming large logs

By truncating the perturbative series at some fixed order, logarithmically enhanced contributions of the form $\ln^m(M^2/q_\perp^2)$ appear. Then the $q_\perp$ distribution need to be evaluated by replacing the partonic cross section as follows

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

Resummed expression

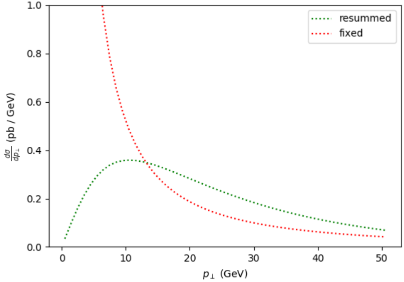
$$\frac{d\hat{\sigma}_{ab}^{\text{res.}}}{dq_\perp^2} = \frac{M^2}{\hat{s}} \int db\, \frac{b}{2}\, J_0(bq_\perp)\, \mathcal{W}_{ab}(b, M, \hat{s}; \alpha_s(\mu_R^2), \mu_R^2, \mu_F^2)$$

Being

$$\mathcal{W}_N(b, M, \hat{s}; \alpha_s(\mu_R^2), \mu_R^2, \mu_F^2) = \mathcal{H} \times exp\{\mathcal{G}\}$$

Resummation in QCD

Resumming large logs



1. FO distribution diverges at small $q_\perp$
2. Sudakov factor kills the divergence
3. Matched at some intermediate accuracy

HTurbo: Fast predictions for Higgs production

Predictions for Higgs qT distribution

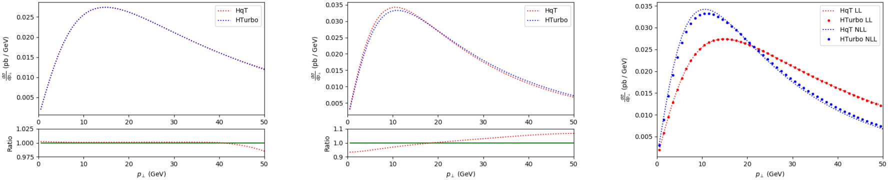
DYTurbo

Modify a fast version for Drell Yan

1. Matrix element
2. Sudakov factor
3. Hard coefficients
4. LO integration

Results

Comparison HTurbo and HqT



- HTurbo produces qt distributions that match HRes and HqT
- Excellent numerical agreement up to NNLO

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

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