Theoretical physics, Machine Learning and Bioinformatics

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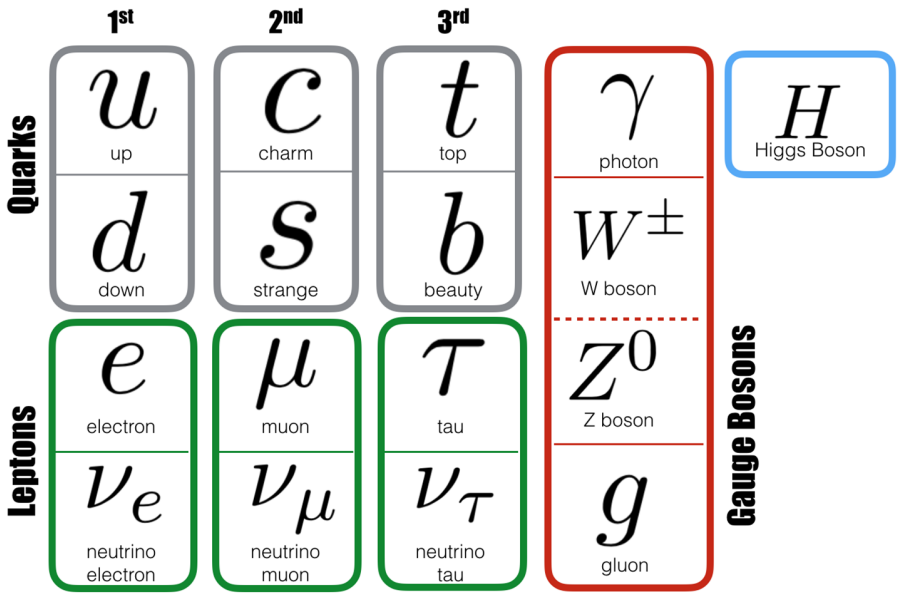
Outline

Quantum Chromodynamics 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

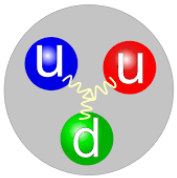
How to explore proton's inner structure?

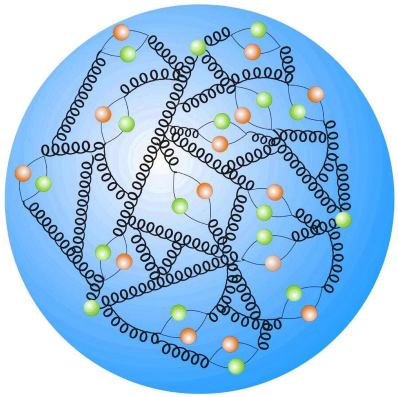
- Point-like projectile on the object $\longrightarrow$ DIS
- Smash the two objects $\longrightarrow$ LHC physics

"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





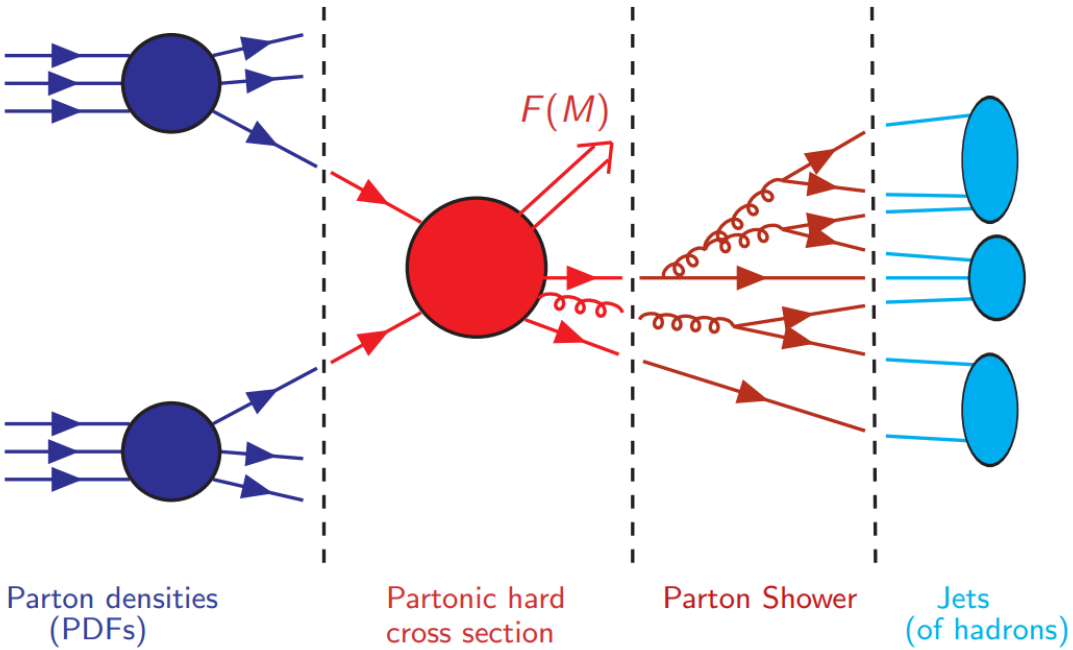
- Hadrons made of partonic objects $\longrightarrow$ non perturbative physics
- Interactions take place only at partonic level

Parton Distribution Functions: probability distribution of finding a particular parton (u, d, ..., g) carrying a fraction x of the proton's momentum

QCD factorization in a nutshell

Factorization theorem

Hadronic Physics $h_1(p_1) + h_2(p_2) \to F + X$



Factorize process as PDFs and partonic (hard) interaction

$$\sigma^{\mathrm{F}}(p_1, p_2) = \sum_{\alpha,\beta} \int_0^1 dx_1 dx_2 \; f_{\alpha/h_1}(x_1, \mu_F^2) * f_{\beta/h_2}(x_2, \mu_F^2) \; * \; \hat{\sigma}^{\mathrm{F}}_{\alpha\beta}(x_1 p_1, x_2 p_2, \alpha_s(\mu_R^2), \mu_F^2)$$

Machine Learning for particle Physics

The N3PDF project

General structure of n3fit

Parton Distribution Functions (PDFs) can not be predicted or measured
PDFs need to be extracted from data!

- Use TensorFlow and Keras to determine the PDFs
- Use Stochastic Gradient Descent n3fit replacing primitive genetic algorithms
- See paper by S.Carraza - J.Cruz-Martinez
  "Towards a new generation of parton densities with deep learning models",
  https://arxiv.org/abs/1907.05075

The HTurbo project

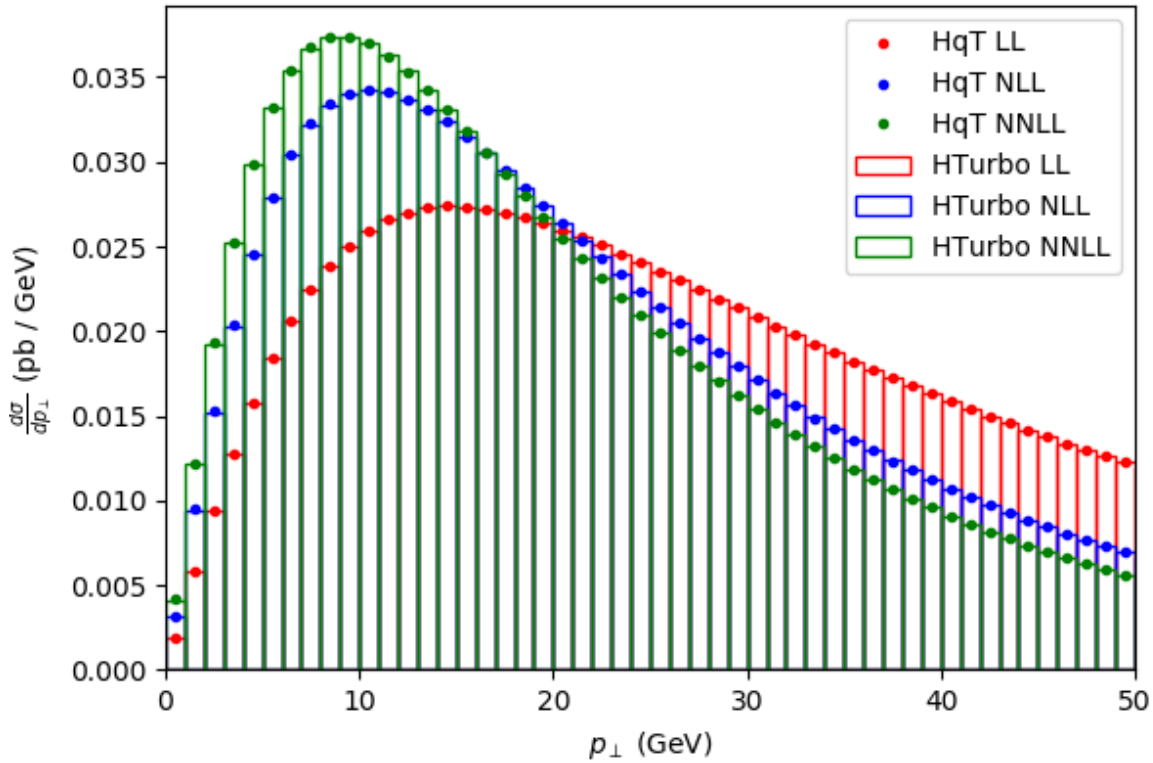
Comparison HRes and HqT - all orders

- Older codes (**HRes**, **HqT**) need 3 days to produce NNLL distribution
- 3 minutes with **HTurbo**! ✓
- Agreement up to NNLL $\longrightarrow$ ready for N^3LL

Bioinformatics

Results

Comparison HRes and HqT - all orders



- Python, C++, R
- Machine Learning
- R analysis, Rpseq, DNaseq

Summary & Conclusions

1. Precise knowledge of PDFs and partonic cross sections are required towards the precision era of the LHC
2. Machine Learning models provide a robust way for PDFs determination optimized through operator implementation in TF
3. We develop a numerical code **HTurbo**, implementing $q_\perp$ resummation for Higgs boson production, which is faster than any of the existing codes
4. Next steps:
   - Validate results at NNLO
   - Include full N^3LO prediction
   - Perform phenomenological studies comparing with LHC data

Thank you!

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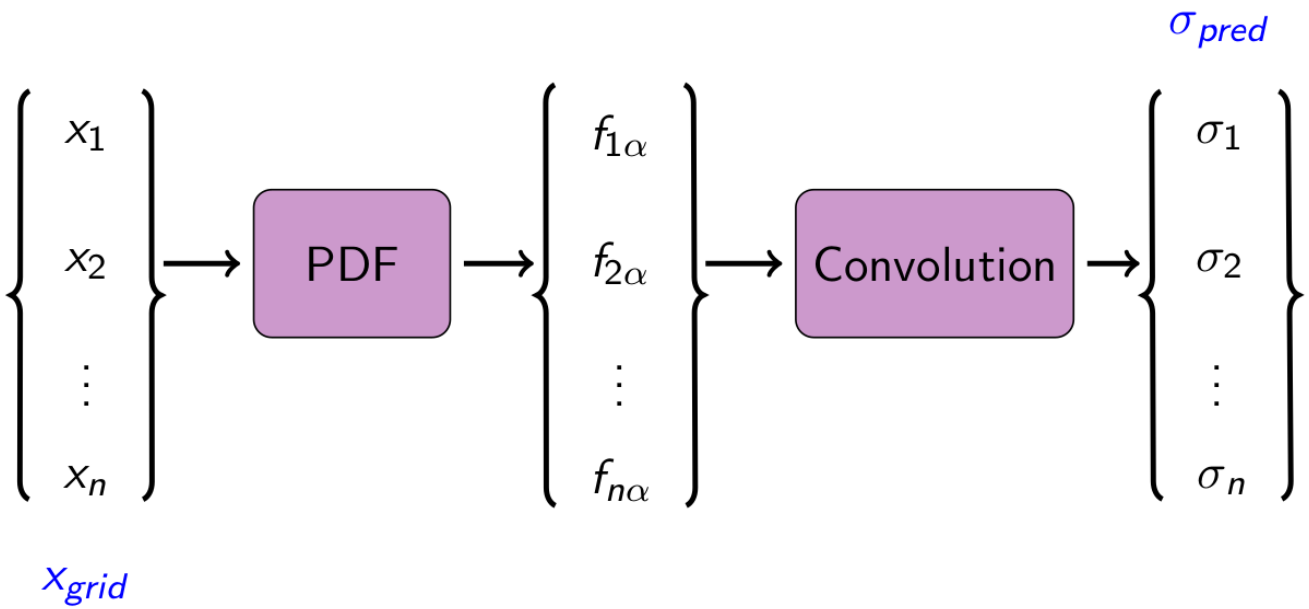
The N3PDF project

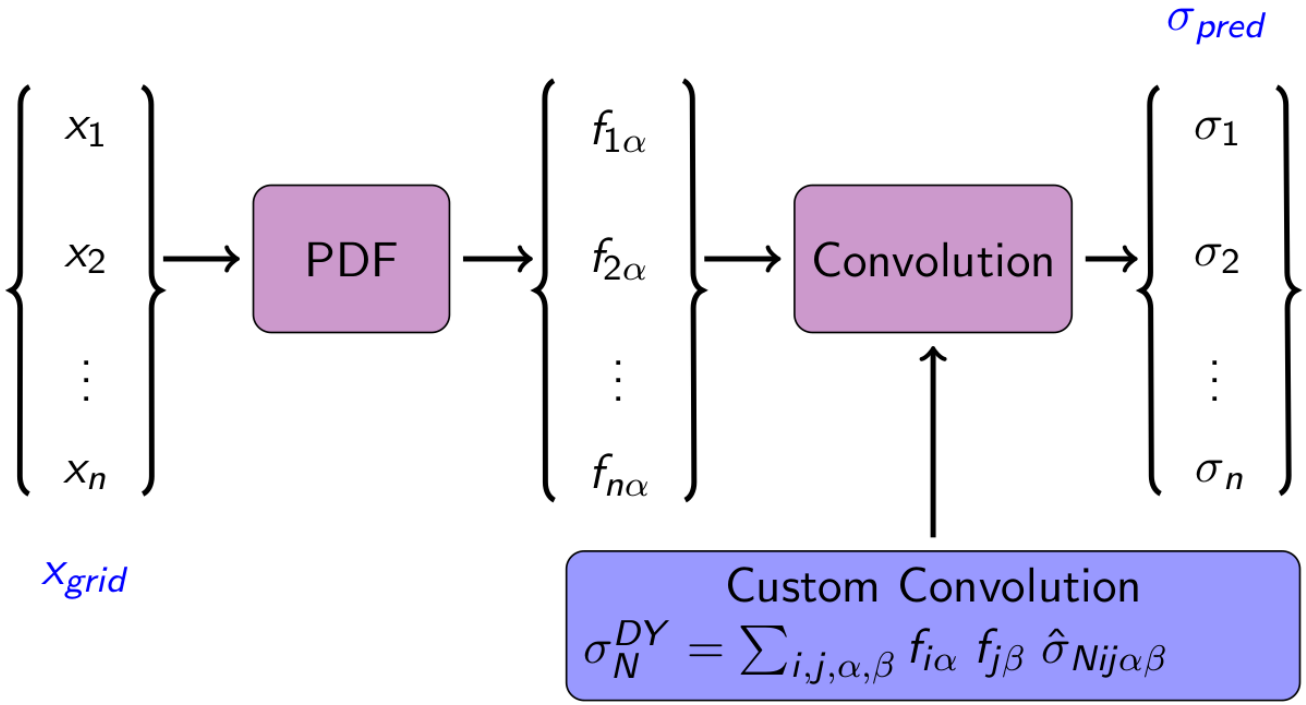
Operator implementation in TF



- Build a NN model to compute σ_{pred} observables from a grid x_i
- Perform χ^2 minimization comparing with data
- Update values of PDF $\longrightarrow$ Fit

The N3PDF project

Operator implementation in TF



1. TF relies in symbolic computation $\longrightarrow$ High memory usage
2. Implement c++ operator replacing the convolution
3. Further details in Urtasun-Elizari et al.
   "Towards hardware acceleration for parton densities estimation",
   https://arxiv.org/abs/1909.10547