Strong Coupling Constant Extraction.

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Introduction

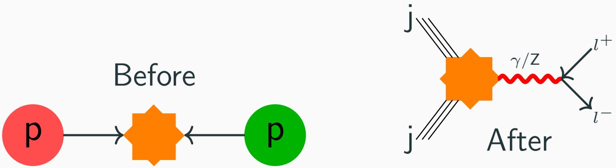
What is α_s ?

The strong force binds quarks and gluons together, and is described by α_s.

Data used in the Extraction

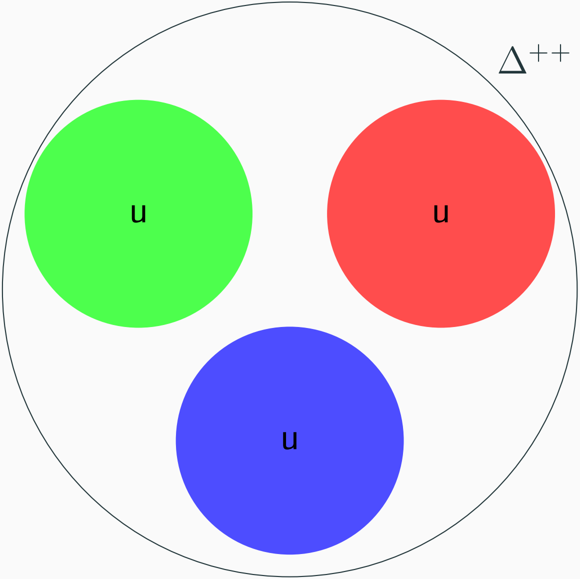
The collision of two protons in the Large Hadron Collider at CERN:

$$pp \xrightarrow{Z/\gamma} l^+l^- + X.$$



Theoretical Context and Motivation

Colour Charge, The Quantum Number



The Standard Model.

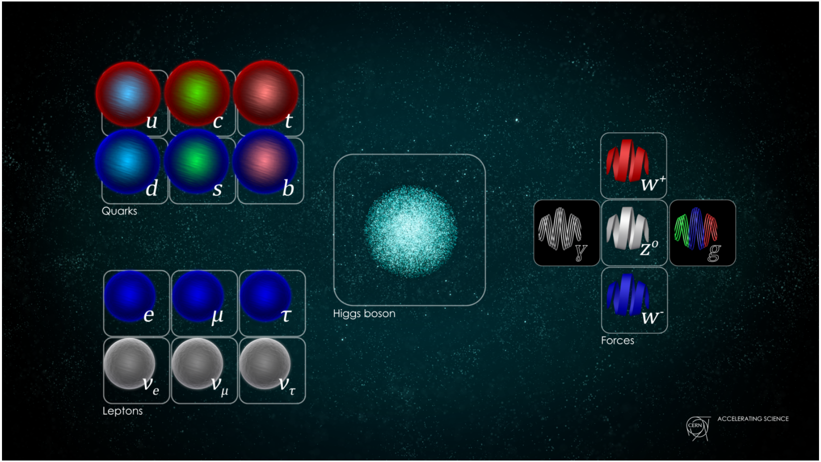


Figure 1: Particles of the Standard Model of particle physics (Image: Daniel Dominguez/CERN)

Colour Confinement and Asymptotic Freedom

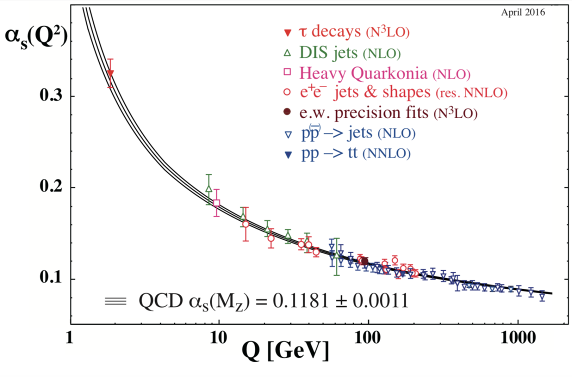


Figure 2: Summary of measurements of α_s as a function of Q the energy scale. The degree of QCD perturbation theory is given in brackets (NLO: next-to-leading order), etc. This graph was produced by the *Particle Data Group*, see [2]

Cross section vs. p_T

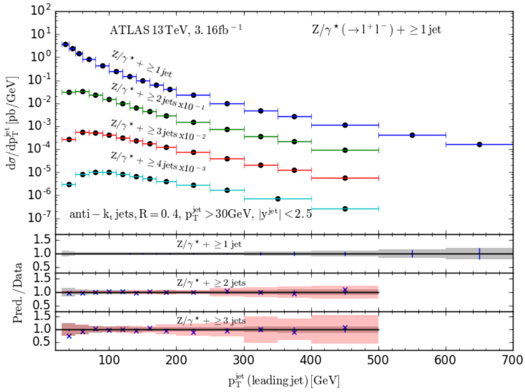


Figure 3: The Cross section for each number of jets inclusive against the leading jet momentum. The PDF set considered here is CT10nlo for $\alpha_s = 0.118$

Pros and Cons of multiple jets

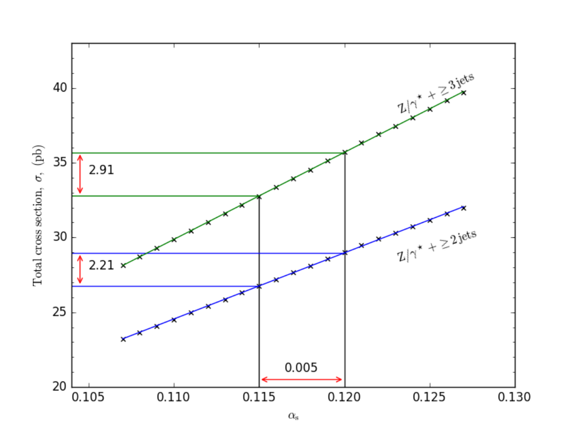


Figure 4: The variation of the error of cross section covered for a given range of α_s. A higher number of jets corresponds to a larger cross sectiin considered hence a lower error on that cross section measurement. The PDF used was MSTW08cl for the central scale.

FastNLO

- We need to compare experimental data with theoretical predictions in order to extract α_s.
- Calculating theoretical predictions is time consuming.

$$\sigma(\mu_R\ \mu_F) = \sum_{i,n} \int_0^1 dx_1\ \alpha_s(\mu_R) c_{i,n}\left(\frac{x_{Bj}}{x}, \mu_R, \mu_F\right) f_i(x, \mu_F),$$

Factorisation and Renormalisation scales

- μ_R: Ultra-Violet Divergences - appear due to large momenta loops.
- μ_F: Infrared Divergences - appear due to i) a virtual or real particles reaching zero momentum ii) a massless particle radiates another massless particle.

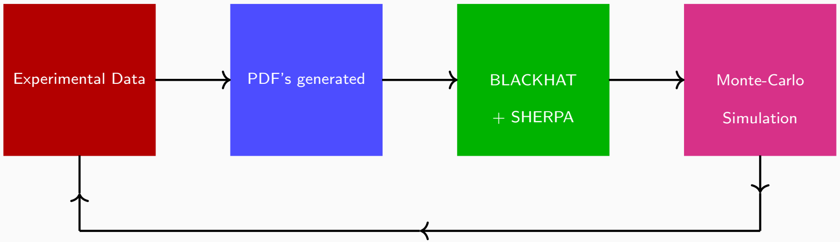
These both lead to α_s depending on these unphysical scales, hence observables should not depend on them.

PDF’s

What are PDF's?

PDF's are number density functions associated with finding certain partons inside the proton.

How PDF’s are generated



Statistical Analysis and Extraction Procedure

Extraction Procedure

$$\chi^2(\alpha_s(M_z)) = (\mathbf{y_t}(\alpha_s(M_z)) - \mathbf{y_d})^T \hat{C^{-1}} (\mathbf{y_t}(\alpha_s(M_z)) - \mathbf{y_d})$$

$$C = C_{exp} + C_{PDF} + C_{theory}$$

The Covariance Matrix

Consider two variables a and b with errors 2 and 3 respectively. Their covariance matrices are:

$$(A)\begin{bmatrix} 4 & 0 \\ 0 & 9 \end{bmatrix} \qquad (B)\begin{bmatrix} 4 & 6 \\ 6 & 9 \end{bmatrix}$$

Independant Variables   Dependent Variables

Calculating C_{exp}

There are three sources of experimental error:

- Statistical
- Systematic
- Luminosity

The sturcture of the Covariance matrix

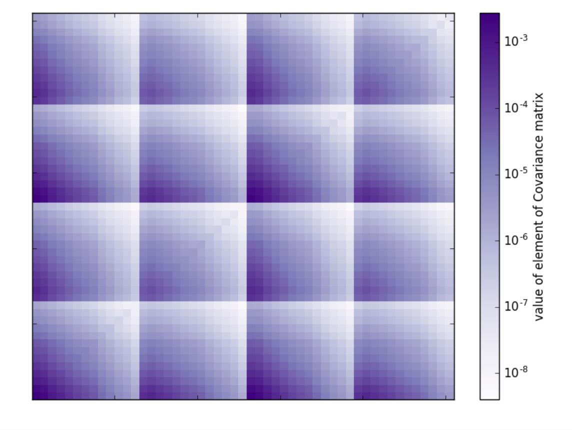


Figure 5: A colour plot showing the structure of the covariance matrix, note that the bottom right corner corresponds to 2 jet electron channel.

Conclusion

Conclusions

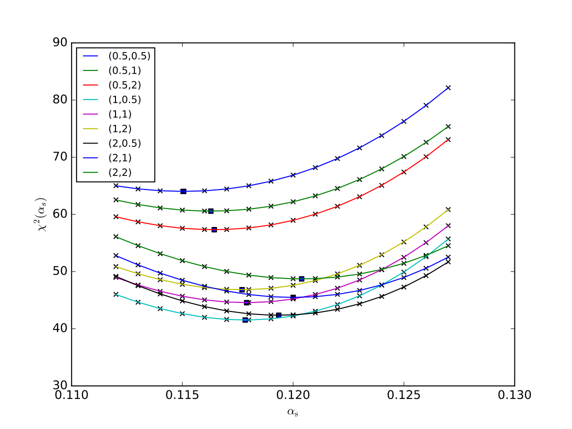


Figure 6: A χ^2 test for the CT10nlo PDF at all scale combinations considered. The blue squares represent the minima of each curve and the scale error is found by the envelope of statistics method.

Questions?

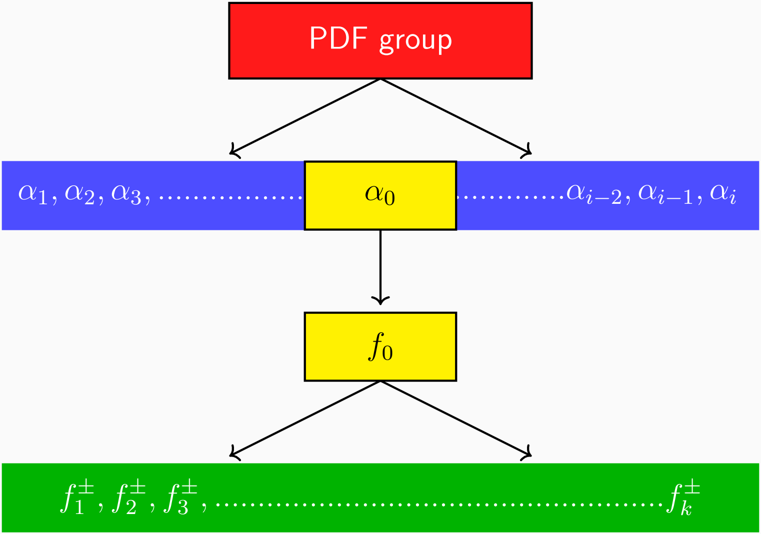
References I

- M. Peskin and D. Schoeder, (2005), *An Introduction to Quantum Field Theory.*
- Particle Date Group, (2017), `http://pdg.lbl.gov/2018/reviews/rpp2018-rev-qcd.pdf`, *Review of Particle Physics: 9. Quantum Chromodynamics*

References II

- M. Johnson and D. Maitre, (2018), https://arxiv.org/pdf/1711.01408.pdf, *Strong coupling constant extraction from high-multiplicity $Z+$ jets observables.*
- S. Alekhin, J. Blumein, and S. Moch, (2012), https://arxiv.org/pdf/1202.2281.pdf, *Parton distribution functions and benchmark cross sections at NNLO, pg 44.*

The Structure of PDF's



Calculating C_{PDF}

$$\Delta\sigma^{+}_{PDF} = \sqrt{\sum_{k=1,n_{PDF}} \max(0, +\sigma_{k,+} - \sigma_0, +\sigma_{k,-} - \sigma_0)^2} \quad [4] \tag{1}$$

$$\Delta\sigma^{-}_{PDF} = \sqrt{\sum_{k=1,n_{PDF}} \min(0, -\sigma_{k,+} + \sigma_0, -\sigma_{k,-} + \sigma_0)^2} \quad [4] \tag{2}$$

Calculating C_{PDF} for general α_s

$$C_{\%} = \frac{C^{i,j}_{PDF}(\alpha_0) \times 100}{\sigma^i_0 \times \sigma^j_0}, \tag{3}$$