Karlsruher Institut für Technologie

Bundesministerium für Bildung und Forschung

Determination of α_s from inclusive jet cross sections

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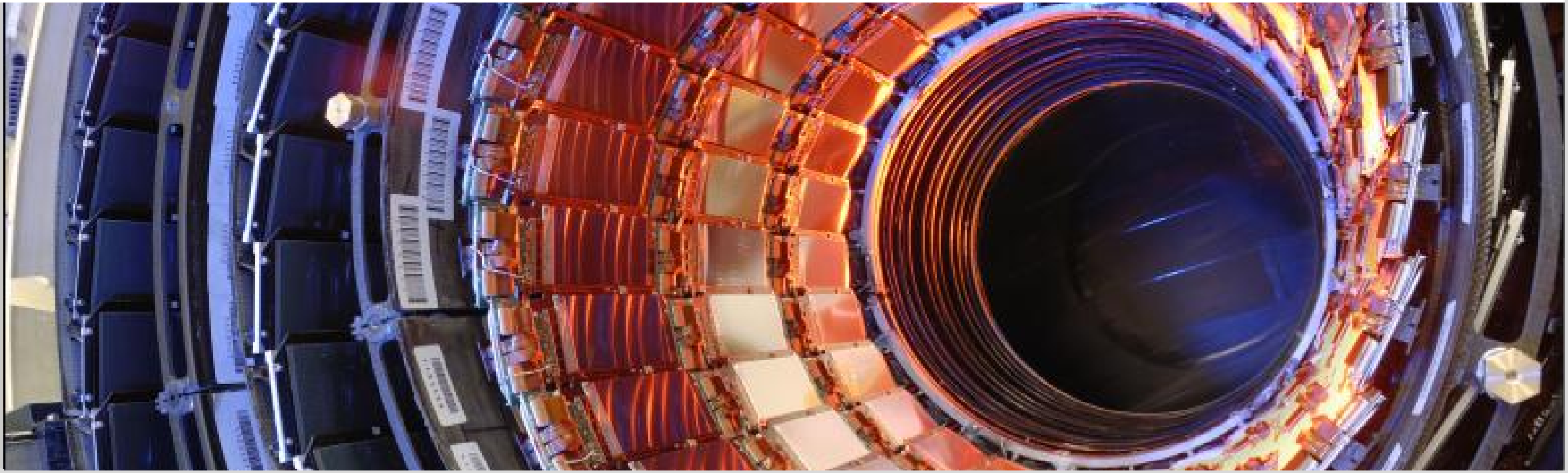
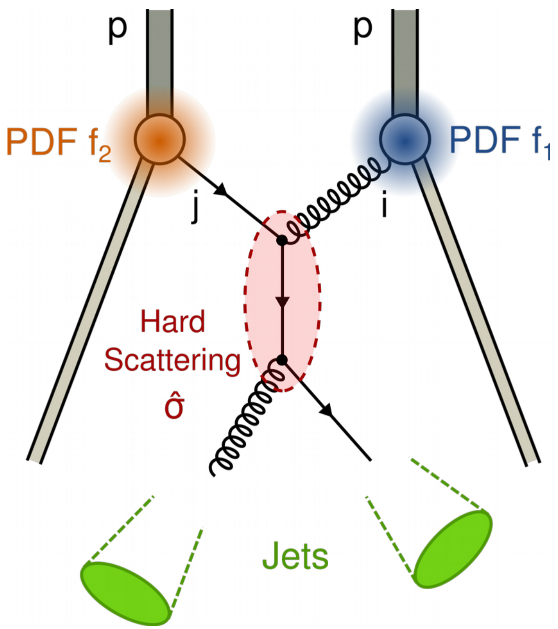


Introduction

- gaining precision:
  - α_s is a fundamental physical parameter, but it is only known to ~ **1%**
    → room for improvement
  - many processes depend on $\boldsymbol{\alpha_s}$ → large impact



- understanding of fundamentals:
  - proton structure → **Parton Distribution Functions**
  - hard parton scattering → strong force at different scales
  - jets → experimental handle on QCD in the final state

→ determine $\alpha_s(M_Z)$ using **inclusive jet cross sections**

- high production cross section
- definition unambiguous, independent of process and experimental choices
- many measurements available

Challenges

NLO calculation
→ missing higher orders?

PDF $\alpha_s(M_Z)$ dependence

sensitive to $\alpha_s(M_Z)$

perturbative expansion

convolution with PDFs

hard process cross section

theory predictions

$$\sigma_{pp} = \sum_{n}^{\infty} \alpha_s^n(\mu_R^2) \sum_{i,j} \int \mathrm{d}x_1\, \mathrm{d}x_2\, f_i(x_1, \mu_F^2)\, f_j(x_2, \mu_F^2) \times \hat{\sigma}_{ij}(x_1 x_2 s, \mu_R^2, \mu_F^2)$$

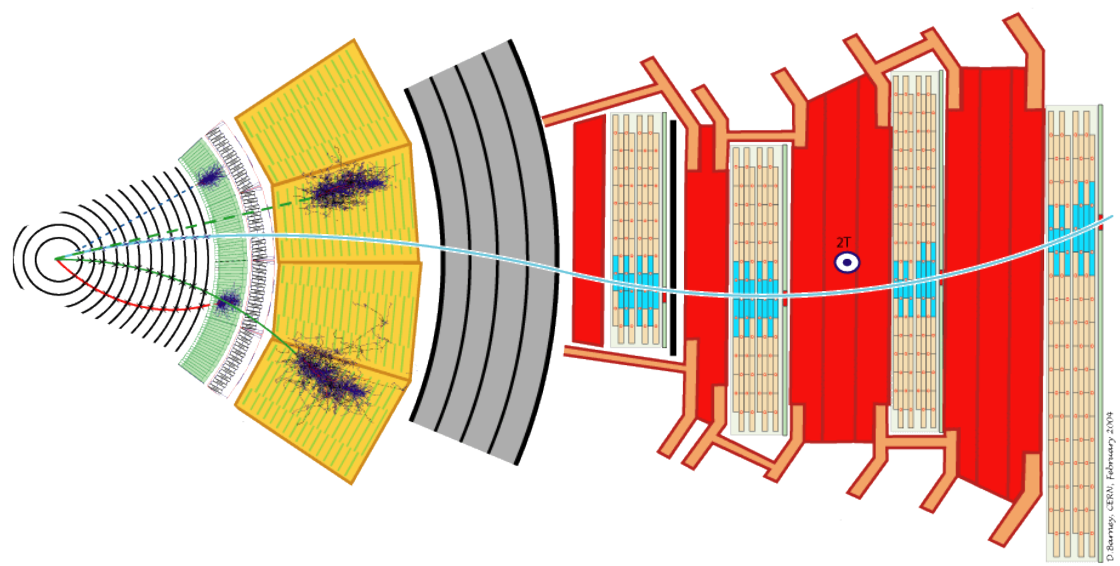
renormalization and factorization scales

processes at different energy scales → RGE/DGLAP evolution

measurement

parameter estimation

data from many experiments → uncertainties and correlations

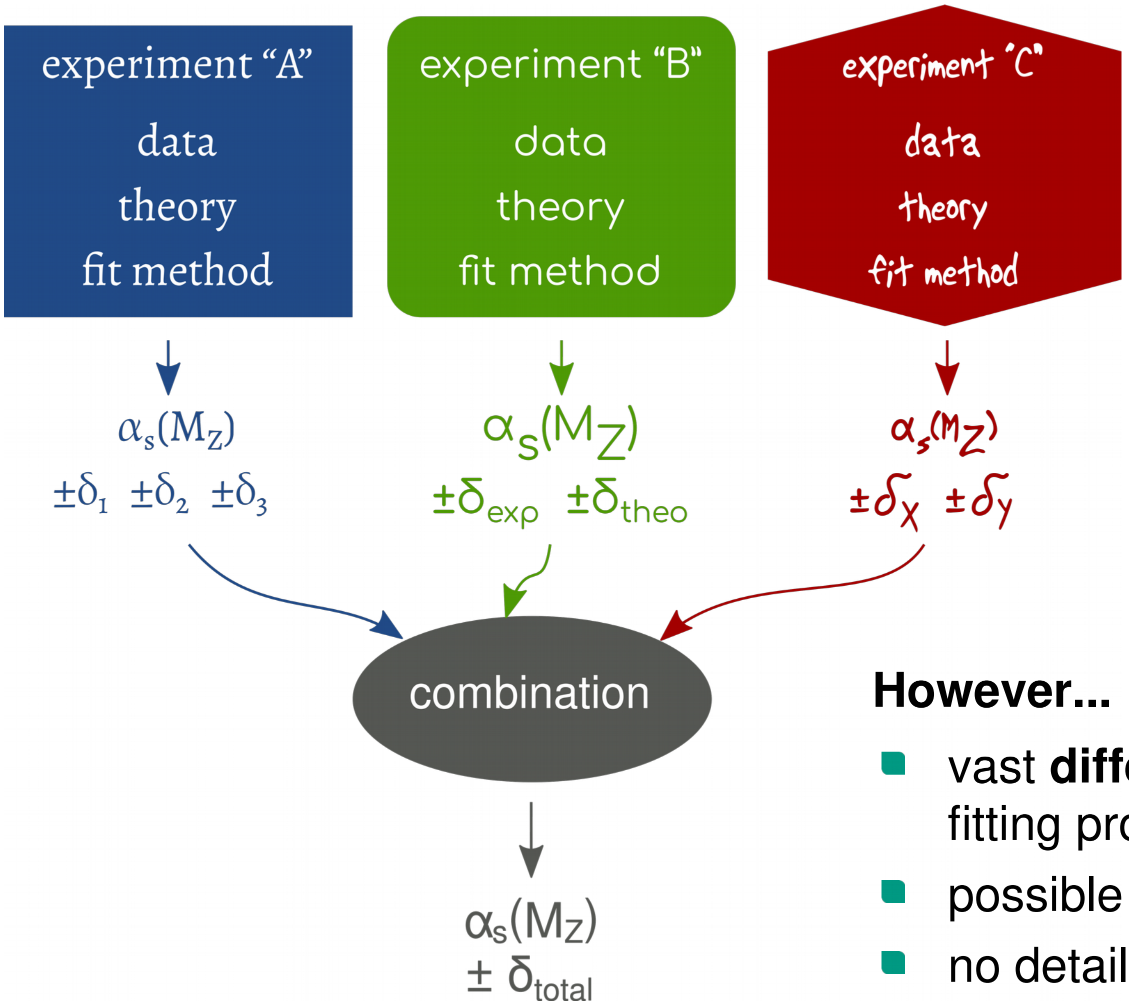


consistent treatment of:
- theory predictions
- experimental data
- uncertainties

estimate and **analyze**:
- $\alpha_s(M_Z)$
- uncertainty on $\alpha_s(M_Z)$

Strategy?

- often: “weighted average” combination of pre-determined values



However...

- vast **differences** in data, theory and fitting procedure
- possible **tensions** can be overlooked
- no detailed uncertainty **breakdown**

Our Strategy

- use data from multiple experiments simultaneously in a consistent fitting procedure

experiment "A" data

experiment "B" data

experiment "C" data

unified theory

(N)NLO calculation ... non-perturbative corrections ... PDFs ... α_s evolution

common fit method

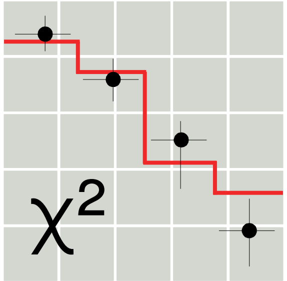
χ^2 definition ... treatment of uncertainties on data, theory ... estimation of uncertainties on α_s

$$\alpha_s(M_Z) \pm \delta_a \pm \delta_b \pm \delta_c$$

Advantages

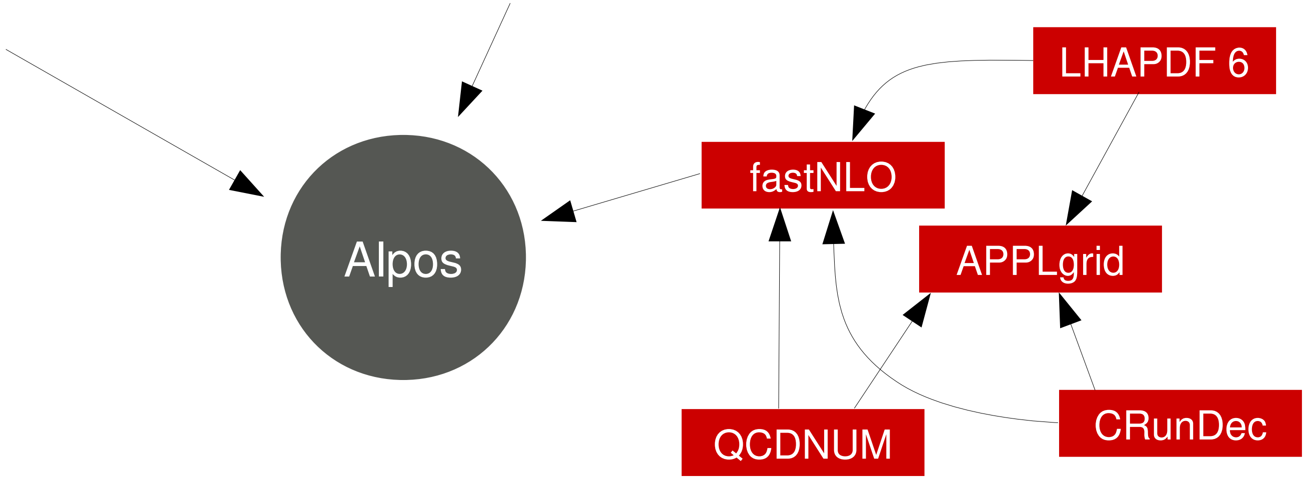
- data and theory on **equal footing**
- can identify and characterize **tensions**
- a single uncertainty model
  → uncertainty decomposition possible

New fitting tool – Alpos



fitting procedure
– multiple χ² definitions available
– flexible treatment of uncertainties

data specification
– multiple datasets
– uncertainties
– correlations



interfaces to many software packages:
– many popular tools supported
– consistent propagation of **shared parameters**

Data sets and past determinations of $\alpha_s(M_Z)$

- use **recent double-differential inclusive jet cross section** data:
  - hadron-hadron colliders:
    LHC (ATLAS, CMS)**, Tevatron** (CDF, DØ)
  - lepton-hadron colliders:
    HERA (H1, ZEUS)
  - heavy ion colliders:
    RHIC (STAR)

different initial state

different experimental setups

large phase space covered

- starting point: three **published $\alpha_s(M_Z)$ determinations**
  - CMS — V. Khachatryan et al. “Constraints [...] and extraction of the strong coupling constant [...] at $\sqrt{s}$ = 7 TeV”, *Eur. Phys. J. C* **75** (2015), p. 288. arXiv: 1410.6765 [hep-ex]
  - DØ — V.M. Abazov et al. “Determination of the strong coupling constant [...] at $\sqrt{s}$ = 1.96 TeV”, *Phys. Rev. D* **80** (2009), p. 111107. arXiv: 0911.2710 [hep-ex]
  - H1 — V. Andreev et al. “Measurement [...] and determination of the strong coupling constant α_s”, *Eur. Phys. J. C* **75** (2015), p. 65. arXiv: 1406.4709 [hep-ex]

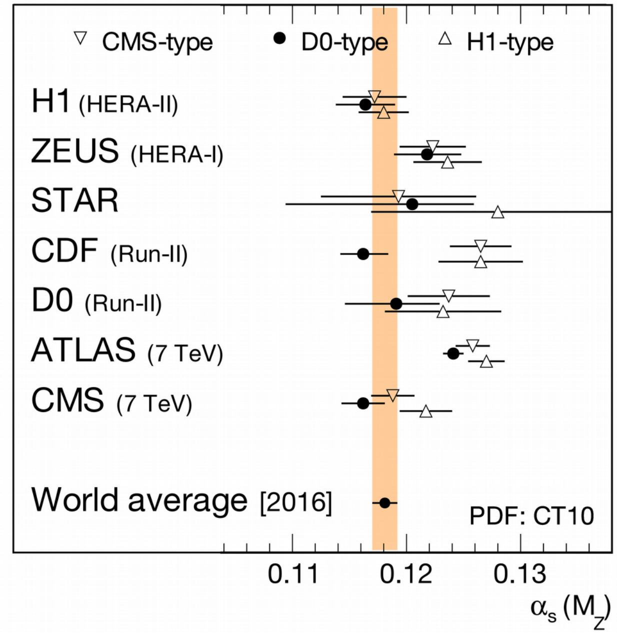
Collaboration fit methods

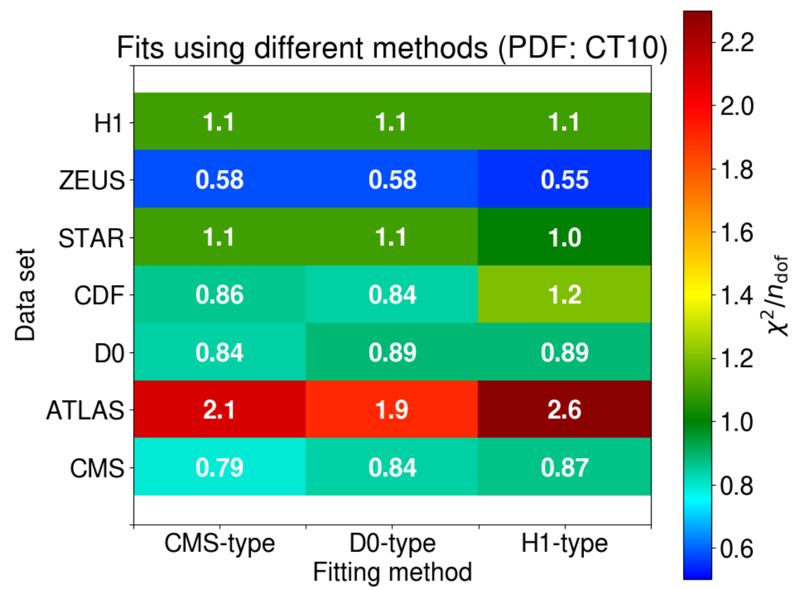
- published $\alpha_s(M_Z)$ determinations from **CMS**, **DØ** and **H1** collaborations
  → different fitting methods

- **reimplement** methods in our own framework
  → consistency check
  → can also apply to **other data**

- methods give mostly consistent results
  - compatible with world average
  - some variation observed

- χ^2 / $n_{\text{degrees of freedom}}$ as fit quality indicator
  - hint at possible issues with some data sets (esp. ATLAS, ZEUS)





Common fit method

- fit all data sets with a **consistent fitting method**
  - direct minimization of χ^2 quantity:

theory

– **NLO** QCD calculation (**NLOJet++**)
– fast recomputation with **fastNLO**
– fixed PDF for $\alpha_s = 0.118$

uncertainties in χ^2 definition

experimental

from non-perturbative effects

$$\chi^2_{\text{unified}} = \sum_{ij} (\ln m_i - \ln t_i) \left[\left(\mathbf{V}^{(\text{rel})}_{\text{exp}} + \mathbf{V}^{(\text{rel})}_{\text{PDF}} + \mathbf{V}^{(\text{rel})}_{\text{NP}} \right)^{-1} \right]_{ij} (\ln m_j - \ln t_j)$$

from PDFs

log-normal distribution

well-suited for data spanning
multiple orders of magnitude

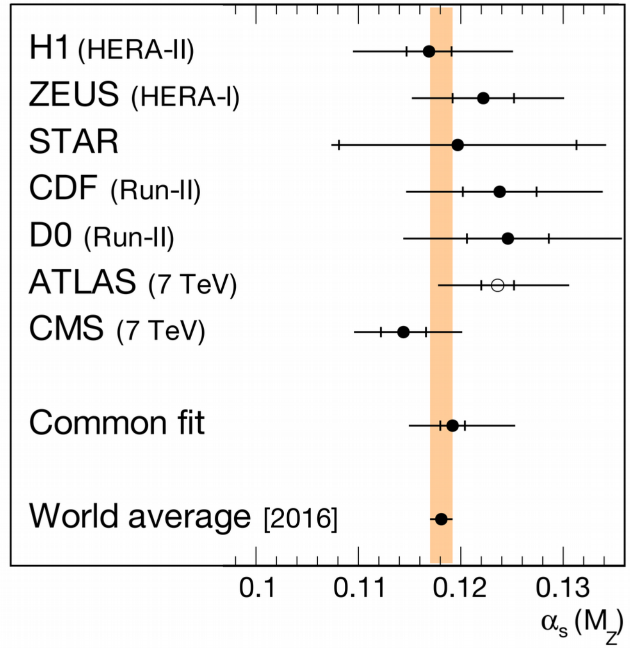
additional uncertainties on $\alpha_s(M_Z)$ by refitting with parameter variations:

choice of PDF set	choice of PDF $\alpha_s(M_Z)$	"scale" (missing higher orders)

Results

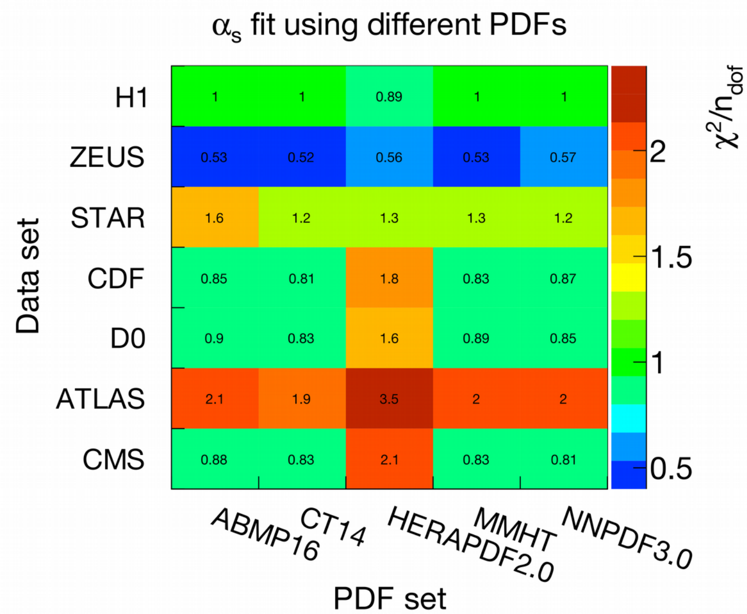
- re-fit all data sets with our **common fit method**
  - enable determination using **all** data sets simultaneously:

$$\alpha_s(M_Z) = 0.1192 \quad (12)_{exp} \quad (5)_{NP} \quad (7)_{PDF} \quad (5)_{PDF\,\alpha_s} \quad (11)_{PDF\,set} \quad \left({}^{+59}_{-38}\right)_{scale}$$



- χ^2/n_{dof} as fit quality indicator
  - HERAPDF2.0 → consistently higher values for all data sets except H1
  - confirm high/low values for ATLAS and ZEUS, respectively

    → conservative option: ATLAS data not included in common fit



Status of inclusive jet production

- data is well described by theory at NLO

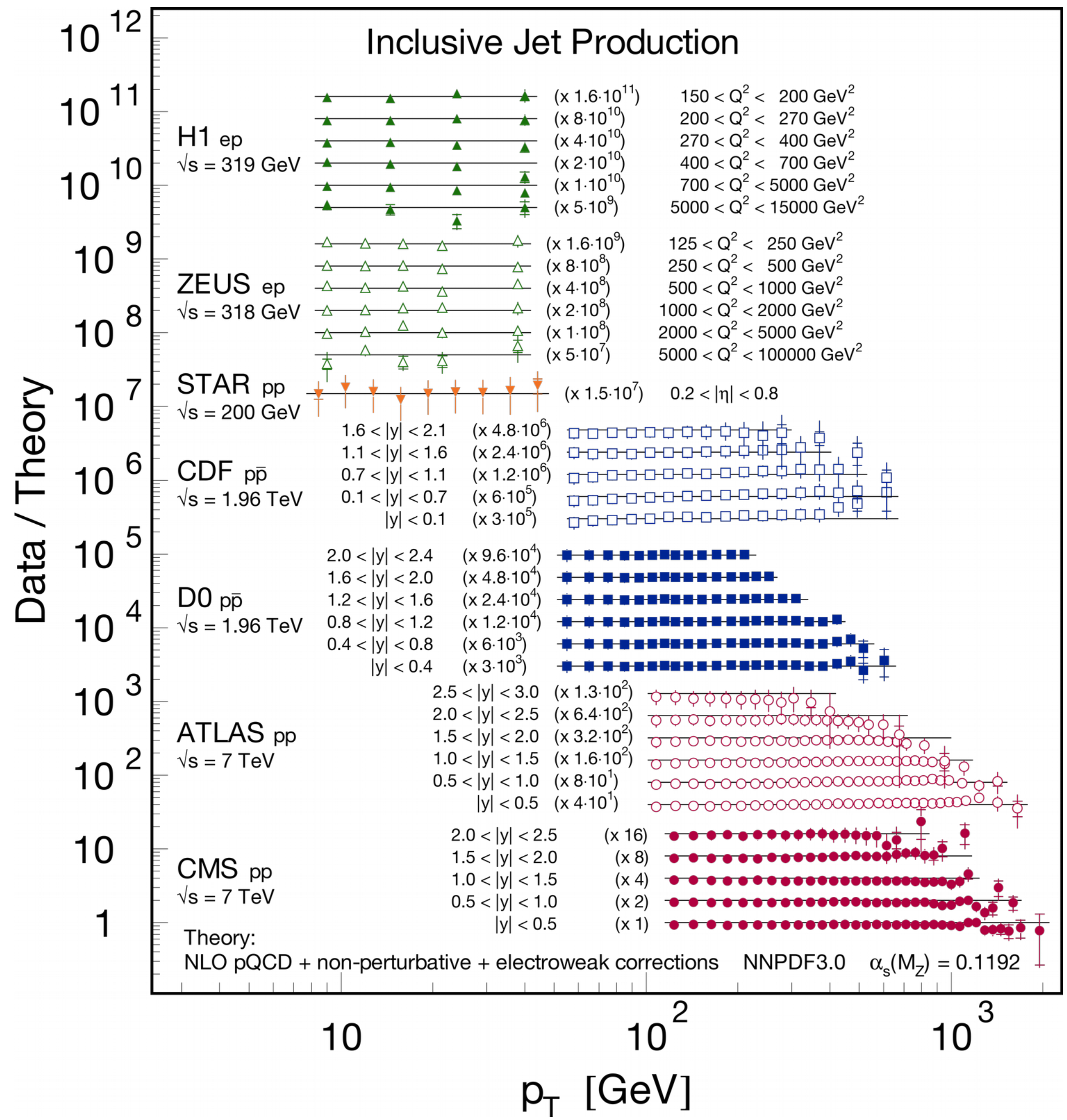
  → *but*: missing higher orders cause of largest uncertainty

- probe of QCD across **>3 orders of magnitude** in p_T

- promising tool for understanding experimental data

  → preparation for studies involving PDFs,

  → in particular, simultaneous PDF+$\alpha_s(M_Z)$ determinations



Summary

- systematic study of $\boldsymbol{\alpha_s(M_Z)}$ at **NLO** using **inclusive jet** cross sections from multiple experiments:

  ATLAS, CDF, CMS, DØ, H1, STAR, ZEUS

- determination of $\alpha_s(M_Z)$ in a **simultaneous** fit to a well-understood data subset:

$$\alpha_s(M_Z) = 0.1192 \quad (12)_{\mathrm{exp}} \; \left({}^{+60}_{-41}\right)_{\mathrm{theo}}$$

  - agreement with the world average
  - reduced experimental uncertainty
  - largest contribution → missing higher orders in perturbation theory
- **consistent** handling of data and theory in a single **common fitting procedure**
  - implemented in new fitting tool **Alpos** → **flexible data/uncertainty specification**, **fastNLO** interface
- to be submitted for publication
- all components in place for a determination at **NNLO**, as soon as theory becomes available